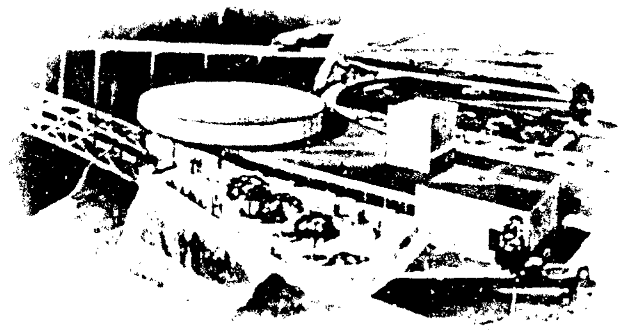
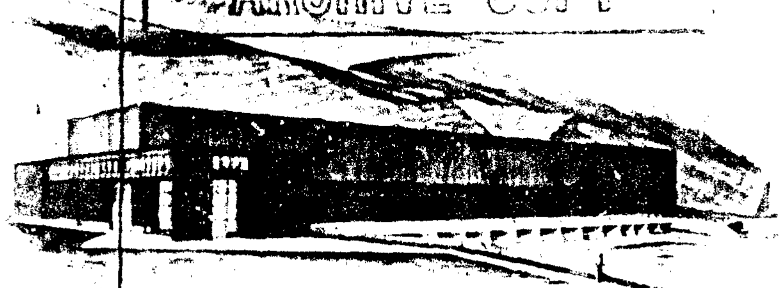




PRECAST CONCRETE FORMS FOR REINFORCED CONCRETE STRUCTURES

REPORT NO. SA-4

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
STRUCTURAL AND ARCHITECTURAL BRANCH

DENVER, COLORADO | OFFICE OF CHIEF ENGINEER | OCTOBER 1965

REPORT NO. SA-4

PRECAST CONCRETE FORMS FOR REINFORCED CONCRETE STRUCTURES

by

William H. Wolf and Arthur J. Power

Structural and Architectural Branch

Division of Design

Office of Chief Engineer

United States Department of the Interior

Bureau of Reclamation

Denver, Colorado

October 1965

ABSTRACT

In the USSR precast concrete integrated formwork has proven more economical than conventional types of removable forms, but in the US under different economic and geographic conditions they can be used to economic advantage only where their full potentialities can be realized. Advantages shown by a study of literature on their design, manufacture, and use are: /(1) Precast concrete forms can be denser, more resistant to erosion and corrosion, less permeable, stronger, and of more uniform quality than cast-in-place concrete, thereby improving concrete surfaces subject to wetting and weather and permitting a reduction of quality and cost of interior concrete. (2) Elimination of form removal and patching of form anchor holes and surface defects reduces cost. (3) Under freezing conditions cast-in-place concrete is protected by the forms and curing of concrete surfaces is eliminated. (4) Construction joints are offset from form joints, stopping leakage and precluding need for waterstops. (5) Bottom faces of slabs and beams can be formed with precast beam elements, reducing support scaffolding and cost./ Disadvantages include increased thickness of a member, special forms needed for blockouts and openings, s orage area needed for the precast units, difficulties in handling and erecting, and possible voids behind facing slabs. These and other factors of design, anchor systems, joints, and bonding should be studied.

DESCRIPTORS-- concrete// *forms/ concrete// *precast concrete/ prestressed concrete/ reinforced concrete/ construction/ erection/ *foreign construction/ design criteria/ foreign design practices/ joint fillers/ hydraulic structures/ quality control/ durability/ permeability/ external forces/ fractures/ buildings/ *concrete structures/ construction joints/ beams/ girders/ joints/ load distribution/ loads/ panels/ slabs/ reviews/ structural design/ structural members
IDENTIFIERS-- USSR/ integrated formwork/ facing slabs

FOREWORD

This report is one in a series the Structural and Architectural Branch issues from time to time to record new technical advances in structural analysis. The intent of the series is to inform Bureau of Reclamation designers of these techniques which may be useful in the design analysis of new Bureau structures.

The reports are reproduced in limited quantities and are made available primarily for use by members of the Structural and Architectural Branch, engineers of other branches of the Division of Design in Denver, and by interested engineers in the Bureau's field offices.

CONTENTS

LIST OF FIGURES

INTRODUCTION

This report covers a study of certain publications on the design, manufacture, and use of integrated precast reinforced concrete units as forms and as protective facing for reinforced concrete structures, especially those partly submerged in water. Precast concrete structural members are not considered here.

This is the initial phase of a study to determine first the economic feasibility of the use of precast forms and second, if such feasibility is proved, to develop a coordinated system for the utilization of precast concrete forming and facing units in the design and construction of reinforced concrete structures. Dimensions, unit stresses, etc., are given in this report in both the metric and English systems, first in the system employed in the source material followed by the other in parentheses. The publications reviewed are listed in the Bibliography at the end of this report and are herein referred to by reference letter only. The subject matter and scope of each publication is as follows:

Reference a.--A comprehensive report covering the development of design, manufacture, and use of precast concrete elements in the construction of all types of hydraulic structures in the Soviet Union and to a limited extent in other countries. The greater part is devoted to precast concrete structural members. Many of the designs described have not actually been built. A good set of illustrations and sketches is included with the report.

Reference b.--A summary of Soviet experience in the use of thin high-quality precast concrete units as protective shells or facing for hydraulic structures. The book covers the design, manufacture, storage, and erection of these units and contains many good illustrations and sketches.

Reference c.--A comprehensive treatise on the design, construction, and erection of all types of formwork utilized in the construction of hydroelectric developments in the USSR. Precast concrete formwork is only one of the several types discussed.

Reference d.--A brief review of past experience in the use of precast slab forms, including that given in Reference a. Included also is a comparative cost study of the construction of a segment of a typical lock chamber wall monolith of uniform cross section using conventional forms and alternate precast concrete forms integrated in the structure. Design of the precast slabs and the assumed method of their erection is described.

Reference e.--A treatise on the advantages to be gained from the use of precast prestressed form panels for massive concrete work on large projects, emphasizing their use in concrete dams. Results of load tests of a slab constructed with precast prestressed concrete slab forms and of a rigid reinforced concrete frame formed on the inside and outside faces with precast prestressed concrete form slabs are described. These tests were made primarily to evaluate the efficiency of the bond between

the precast concrete and the cast-in-place concrete in the structures and the effectiveness of the forms in acting as integral parts of the structures.

ADVANTAGES OF PRECAST FORMS

Precast concrete, under proper conditions of manufacture and control, can be made denser, more resistant to erosion and corrosion, less permeable, stronger, and of more uniform quality than concrete cast in place in the field. These properties are all necessary for structures subjected to submersion in water, hydraulic pressures, the erosive and corrosive effects of water, and to the destructive effects of freezing and thawing cycles. It follows then that improvement of the quality of concrete in the faces exposed to such action will result in lower maintenance and repair costs and longer service life for the structures. The use of precast concrete forms could then be assumed to give the necessary protection to the structure from water action and allow a reduction in the quality and thus the cost of the concrete placed between such forms.

Utilization of precast concrete forms integrated into the completed structure eliminates form removal with its subsequent patching of form anchor holes and surface imperfections and repair of gravel pockets where mortar may have leaked out of the form.

Use of precast concrete facing slab forms provides significant protection from freezing to the cast-in-place concrete and eliminates curing of concrete surfaces under freezing conditions. Thus, the

length of the construction season during which special protection against freezing is required can be increased and winter protection can be simpler and less costly.

Construction joints (except those designed for contraction or expansion of the structure) in the concrete placed in the forms are offset from the precast concrete form joints, virtually eliminating the possibility of leakage through the construction joints and precluding the need for metal or rubber waterstops in the joints. Such offsetting of joints may also be considered to take the place of formed shear keys in the joints except possibly where unusually severe shear stresses exist.

Bottom horizontal faces of slabs and beams and the ceiling faces of large openings in mass concrete sections can be formed with precast elements designed as beams supporting the weight of wet concrete and construction loads above. Thus, form support scaffolding can be limited to perhaps one center support or even eliminated altogether.

The time required for construction can be reduced by the use of precast concrete integrated formwork. Some factors affecting savings in time are as follows:

1. All the formwork required for a structure can be manufactured in advance of concreting, permitting greater flexibility, and continuity in concrete operations. Delays in concreting due to time required for preliminary curing of concrete preceding

form removal and removal and reerection of forms can be eliminated.

2. Scaffolding, normally required to support overhead removable forms, can be partly or completely eliminated, thus saving the time involved in its erection.

3. Further flexibility and consequent savings in time can be realized by the use of precast forms for expansion joint faces. Both faces at the joint can be formed thus permitting placement of concrete in adjacent blocks independently of each other.

4. Curing of formed concrete faces is eliminated.

5. The quantity of building debris to be removed from the site such as formwork, scaffolding materials, and form bracing is sharply reduced.

DISADVANTAGES OF PRECAST FORMS

A major problem encountered in the use of integrated precast concrete forms has been the attainment of satisfactory joints between the form units--joints that are sound, strong, impermeable, and of good appearance, and that do not require an excess amount of time or labor to complete. Joints must be especially well made if a low quality concrete is to be used to fill between the form slabs. Proper curing of the joints requires special attention and care.

A certain amount of reinforcement steel over and above that required for the structure is required for precast concrete formwork

to strengthen the slabs to withstand handling stresses, to transfer wet concrete loads to the slab anchors and ties, and to anchor the slab permanently to the cast-in-place concrete.

In some cases, the precast concrete slab is in the tension face of a member and for design purposes only provides an increased depth of cover over the structure reinforcement, either reducing the effective depth of the member and increasing the amount of reinforcement required or necessitating an increase in the overall thickness or depth of the member.

Where concrete faces are interrupted by blockouts, pipes, anchors, waterstops, or other embedded material it is necessary to provide special precast form units. Maintenance of the impermeability factor at such locations presents a problem if low quality concrete is being placed in the forms.

To facilitate and speed up form erection, a large storage area for the precast units is required at the construction site, and lack of such storage can be a serious handicap to the realization of the full potential of the precast concrete form system in saving construction time.

Special precautions must be taken in handling, storing, and erecting precast forms to protect their edges from damage and to prevent cracking the units.

Larger cranes or other handling equipment may be required for the precast concrete forms than would be needed if conventional removable forms were used.

Locating and filling voids that might occur behind facing slabs is costly and time consuming. Careful placement of the fill concrete in the forms and a joint design that prevents loss of mortar can minimize the occurrence of such voids.

ECONOMIC CONSIDERATIONS

Based upon statements by Soviet engineers in their publications and the cost study described in the U.S. Army Corps of Engineers' report, it is concluded that the cost of a reinforced concrete structure utilizing integrated precast concrete forms will generally be greater than if the more conventional types of removable forms are used. It follows then that if precast concrete forms are to be used to economic advantage, they must be considered only where their full potentialities can be realized. In making a study of the proposed use of precast concrete forms for a particular structure, the following points should be considered:

1. Site characteristics.--In an area with long severe winters and a short summer construction season, the amount of work accomplished during the construction season may be increased by the use of precast concrete forms manufactured in advance. Erection of the forms can begin before the weather has warmed enough to permit placing concrete without heating. Such a system might be more economical than winter concreting. Adequate onsite storage for the precast concrete forms should be available.

2. Structure characteristics.--Massive concrete sections, elements requiring exceptionally high scaffolding or shoring to support forms, and large numbers of identical form units are features favorable to the use of precast concrete forms.

3. Manufacturing facilities.--The feasibility of using precast concrete forms in small to medium size structures is probably dependent upon the availability of existing plants within a reasonable haul distance from the construction site, suitable for the manufacture of precast units. For large structures, construction of a plant for manufacture of the precast concrete units at or near the structure site may be justified. Facilities should be provided to produce high quality form units at a rate consistent with the requirements of the job. Plant efficiency has considerable bearing on the cost of the units.

4. Form design.--Units should be as large as practicable within the limits of the capacities of the usual handling equipment available. Large size units reduce handling costs and reduce length of joints. The number of different sizes of units should be kept to a minimum. Odd-shaped units or units with curved surfaces should be avoided except in special cases.

To give the units needed strength, a certain amount of reinforcement is required. However, this reinforcement should be held to a minimum.

Consideration should be given to the use of beam type forms, thick slab panels containing structure reinforcement, or prestressed concrete slab forms in areas such as tension sides of building elements. Here, conventionally reinforced thin slab precast concrete forms may increase the reinforcement requirements of the member by reducing its effective depth without contributing materially to its strength.

The joints between units should be designed to reduce to a minimum the work required to finish the joint after concrete placement in the structure. Forms should be designed so that high scaffolding or shoring is not required.

5. Form erection.--The method of erecting and anchoring the forms in place should be developed to make full use of the main structure reinforcement. Some stiffening of the reinforcement cage may be required. Means should be provided for easy and rapid alinement of the precast units.

6. Structure design.--Where possible, due to offsetting of facing joints and structure concrete construction joints, formed keys and waterstops in the construction joints of hydraulic structures should be omitted. Cast-in-place concrete construction joints should be sloped to a maximum slope of 5 to 1 to eliminate short vertical joints.

In some cases, the volume of cast-in-place structure concrete may be large enough to realize an appreciable savings in

cement by reducing the concrete quality consistent with the strength requirements to meet the loads imposed on the structure. Design of concrete structural elements should include the effects of the integrated precast concrete form units, and full advantage of their properties should be taken wherever possible. Details and dimensions of structures should be proportioned to hold to a minimum the number of sizes and shapes of precast units required.

7. Other.--Where time allowed for construction is unusually short owing to power commitments for hydroelectric powerplants or to other considerations, it may be worth additional cost to utilize precast concrete forms in the construction to facilitate meeting the completion dates.

TYPES OF UNITS

Three general types of precast concrete integrated form units have been developed for concrete structures: thin facing slabs, large panel facing slabs, and bearing facing slabs. Special massive units developed for concrete dam facings are not included here.

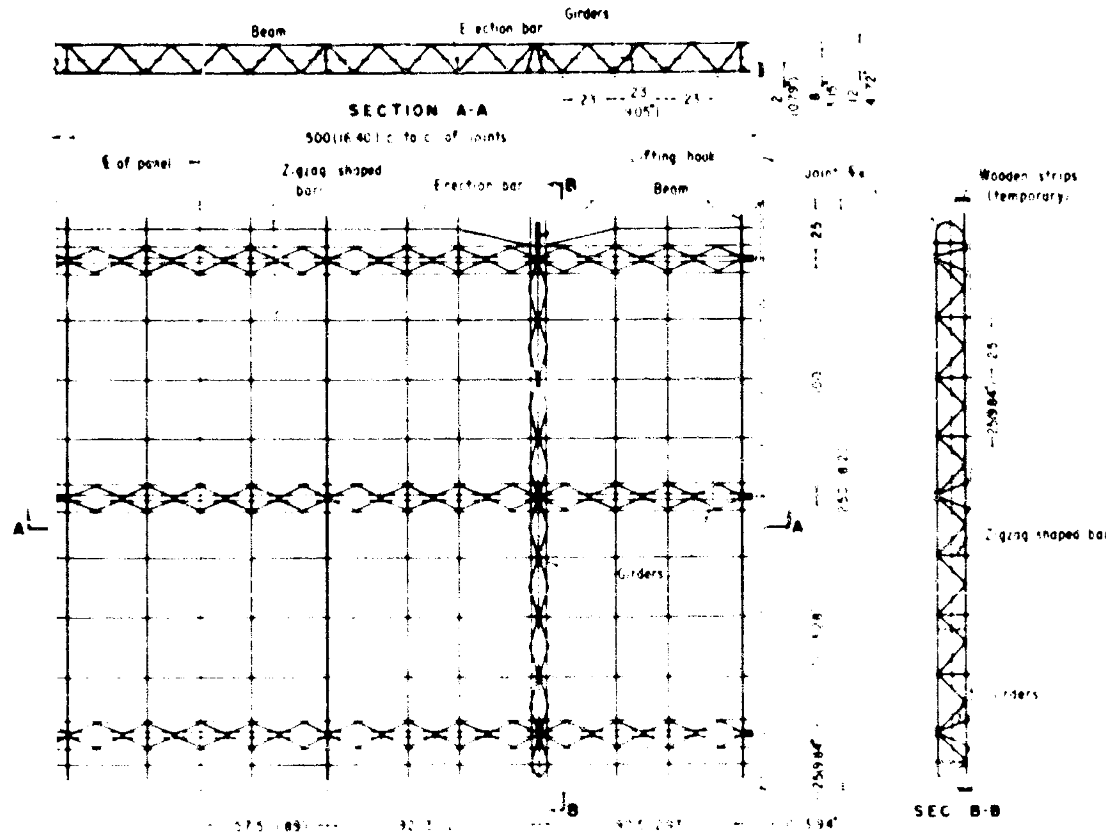
Thin facing slabs, as used for vertical faces, are based on the principle that the slab should be independent of the structure reinforcement and as thin as the required characteristics of strength, durability, and impermeability permit. This type of unit

incorporates small welded truss beams and girders fabricated from reinforcing steel and partially embedded in the slab to provide rigidity and prevent cracking during handling and erection. Anchors or ties taking the thrust of wet concrete against the forms are attached at the intersections of transverse and longitudinal girders. These intersections also serve as lifting points for the units. Additional zigzag bent bars and straight bars project from the back face of the slab to anchor it to the structure concrete. The reinforcement in these slabs is of little if any value in resisting the loads on the completed structure.

These units have been constructed in sizes up to 2.50 meters (8.2 feet) by 5.00 meters (16.4 feet) and thicknesses from 8 to 10 centimeters (3.15 to 3.94 inches). On the basis of inspection of 2.50-meter by 5.00-meter by 8-centimeter slabs 10 years after installation in two developments, Soviet Engineers Moiseenko and Sedov recommend the standard slab size be reduced to 2.00 meters (6.6 feet) by 4.00 meters (13.1 feet) and the thickness increased to 10 centimeters (3.94 inches) to reduce cracking.

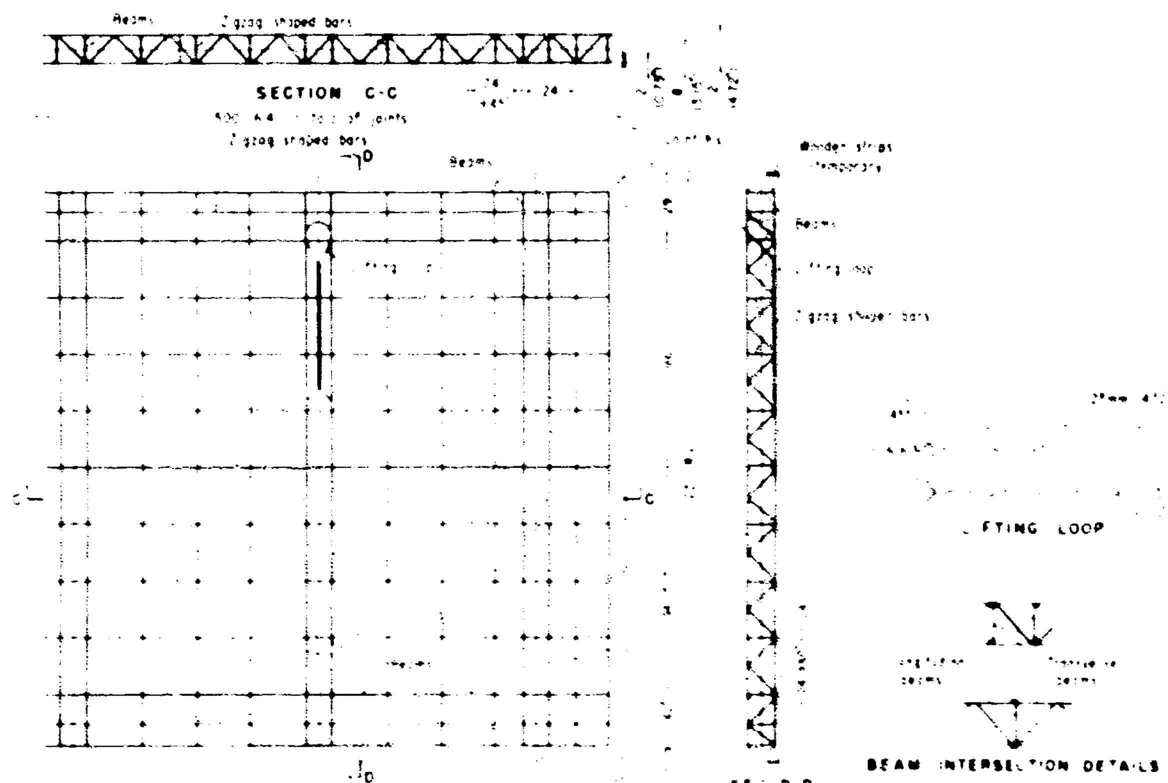
Two variations of reinforcement for a 2.50-meter by 5.00-meter by 8-centimeter slab, as shown in Figure 1,* are typical for thin facing slab units. A reinforcement beam consists of a zigzag-shaped bar with a straight bar welded to each side to form a truss. A girder is made up of two beams welded together at the top chord and spread apart at the bottom chord forming a triangular cross

*Dimensions in this figure and subsequent figures are given in centimeters followed by English units in parentheses.



PART PLAN

(a) TRIANGULAR GIRDER SECTION SYSTEM



PART PLAN

(b) DOUBLE BEAM SYSTEM

THIN CONCRETE FACING SLABS

section. Zigzag bars are installed to anchor the slab to the structure concrete and are fixed in position by straight "erection" bars welded to the tips or bend points. Beams stiffen the reinforcement, and girders transmit the pressure of the wet concrete to the ties to which they are fixed.

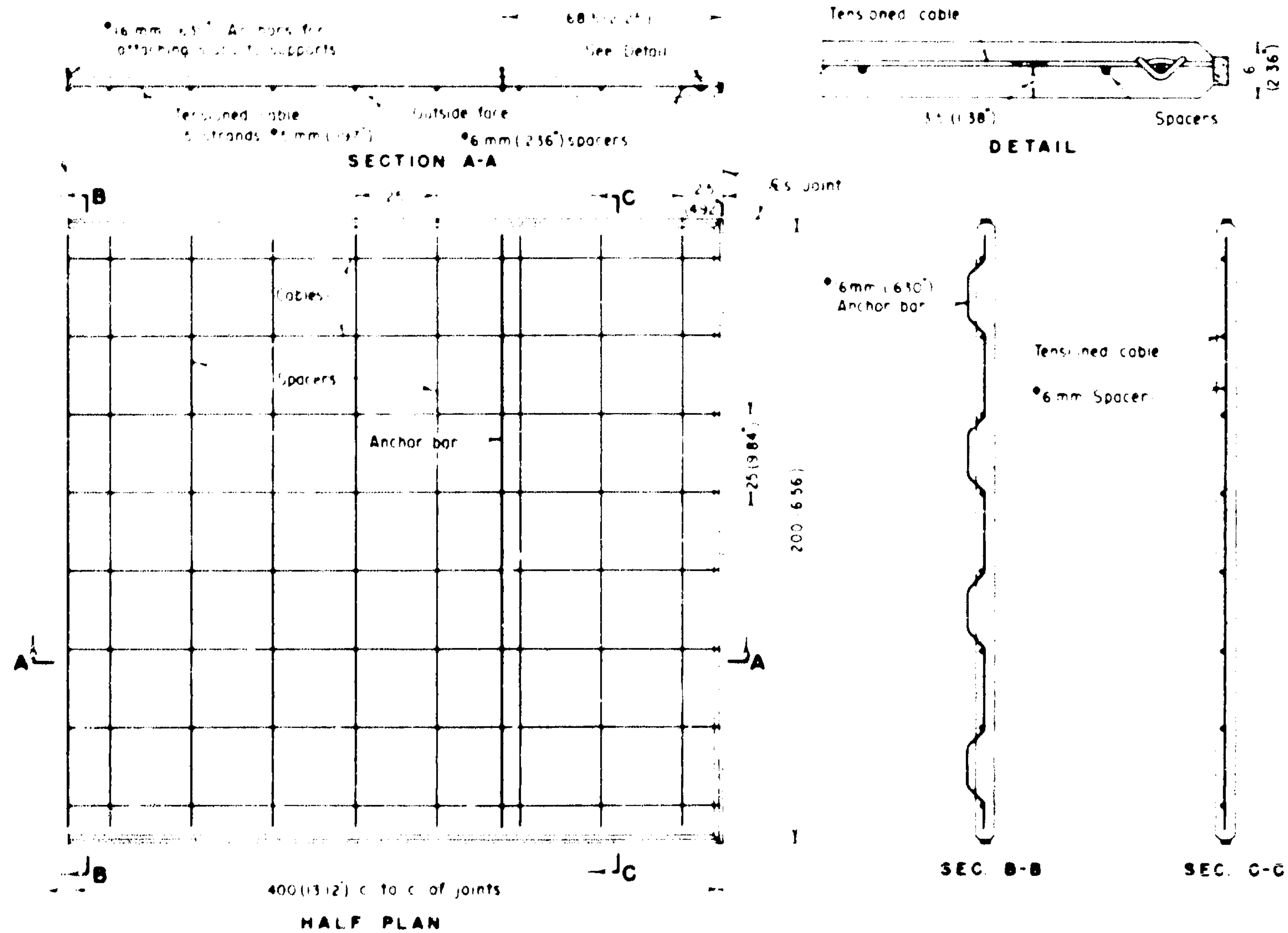
In Figure 1(a) the longitudinal reinforcement consists of 3 girders 12 centimeters (4.72 inches) high and 8 zigzag bars at 25-centimeter (9.85-inch) centers located between girders. Transverse reinforcement includes 2 girders 10.5 centimeters (4.13 inches) high, 4 beams, and 10 "erection" bars. In some cases 6 millimeter- (0.236-inch) cable wire anchors were installed in the rear of the slab to resist water pressure between the slab and the structure concrete. The reinforcement shown in Figure 1(b) is similar except that flat parallel beams in pairs are used in place of the triangular section girders, bar size and spacings vary, and the lifting hook detail is different.

On the basis of their examination of installed units, Engineers Moiseenko and Sedov recommend the addition of anchors around the periphery of the slabs to prevent them from becoming detached from the structure concrete due to shearing stresses set up by shrinkage. The total weight of the reinforcement per slab unit as shown in Figure 1(a), not including periphery anchors, was 65 kilograms (143.3 pounds), equivalent to 5.2 kilograms per square meter (9.6 pounds per square yard). Other figures were given ranging

from 6.8 to 10 kilograms per square meter (12.5 to 18.4 pounds per square yard).

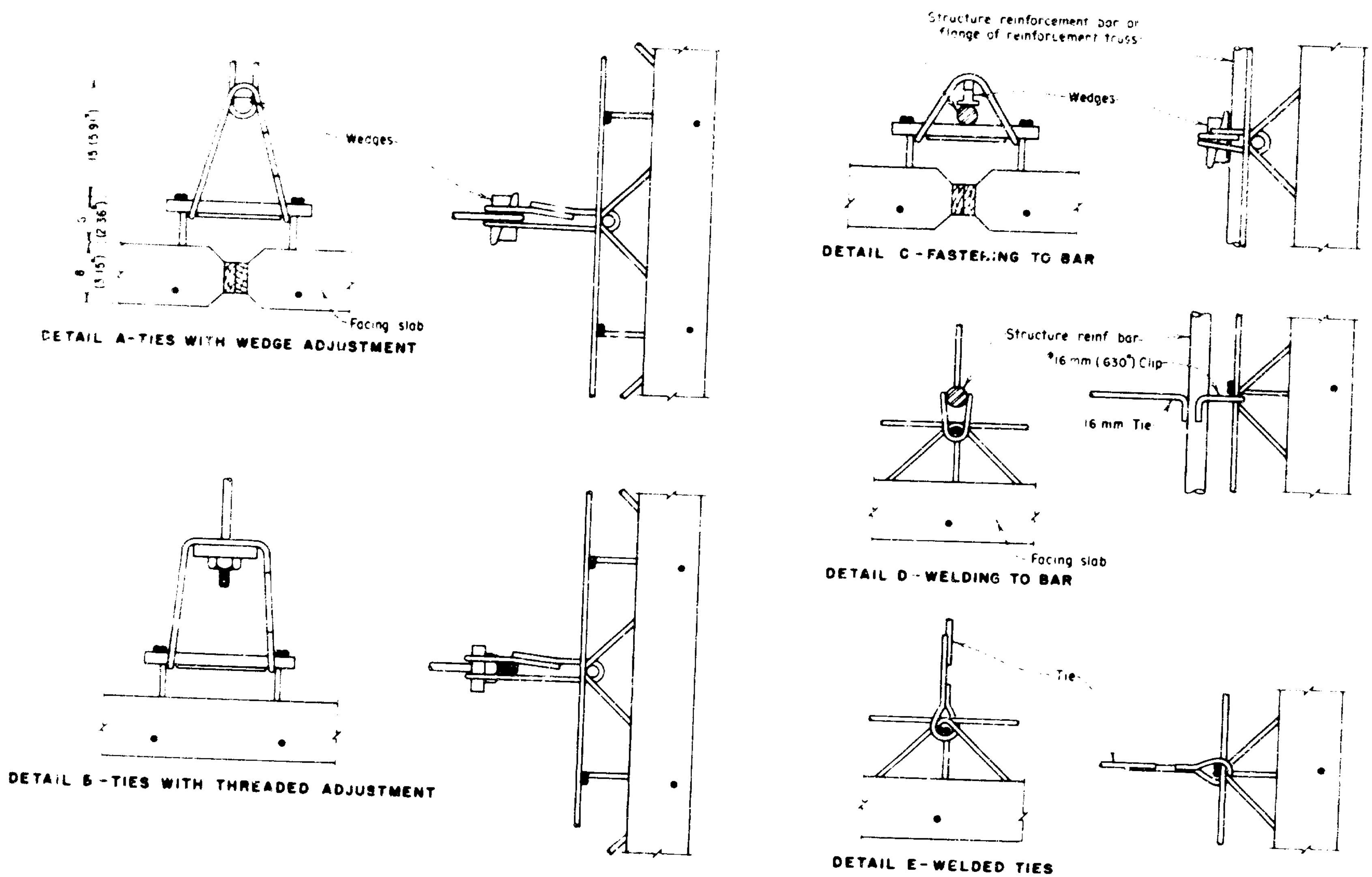
Prestressed reinforcement in facing slabs would increase the water tightness of the units and reduce or eliminate cracking. It might also permit a reduction of slab thickness and stiffening reinforcement. One design prepared by Gidroproyekt for a prestressed slab 2.00 meters (6.6 feet) by 4.00 meters (13.1 feet) by 6 centimeters (2.36 inches) thick (Figure 2) showed an estimated cost increase of 25 percent over the previously described thin slabs.

Thin facing slabs are set in position, using lifting hooks attached to the girders or beams (see Figure 1), after the structure reinforcement is placed. The slabs are then tied to the reinforcement which may require special bracing to support the forms. Following this, steel rods are connected to the girder intersections of opposing slabs to resist the lateral pressure of fresh concrete. Welded connections are often used as they provide easy adjustment of the tie length and uniform tension in the ties. Threaded or wedged connections are also used. See Figure 3. Usually one tie per square meter (10.8 square feet) of face area is provided with the end ties not more than 33 centimeters (13.8 inches) from the edge of a slab. Ties are set normal to the faces to avoid longitudinal stresses in the facing. Where opposing faces are too far apart for connecting ties, diagonal ties to anchors in previously



PROPOSED DESIGN - PRESTRESSED CONCRETE FACING SLAB

FIGURE 2



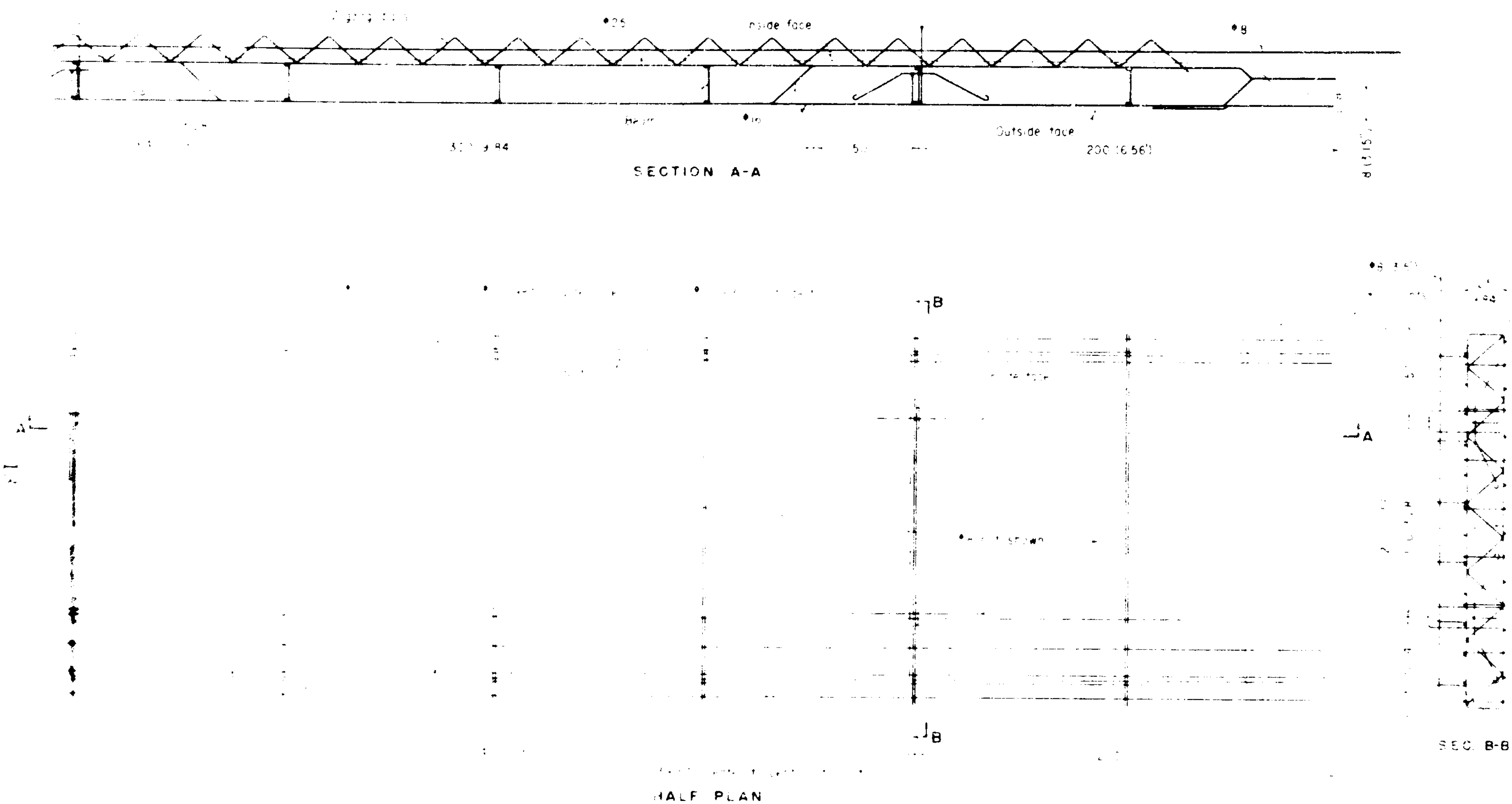
TYPICAL SLAB CONNECTIONS TO TIES AND REIFORCEMENT

FIGURE 3

placed concrete may be used. If thin forms are to be used for horizontal surfaces they must be supported on scaffolding or suspended from special beams or girders.

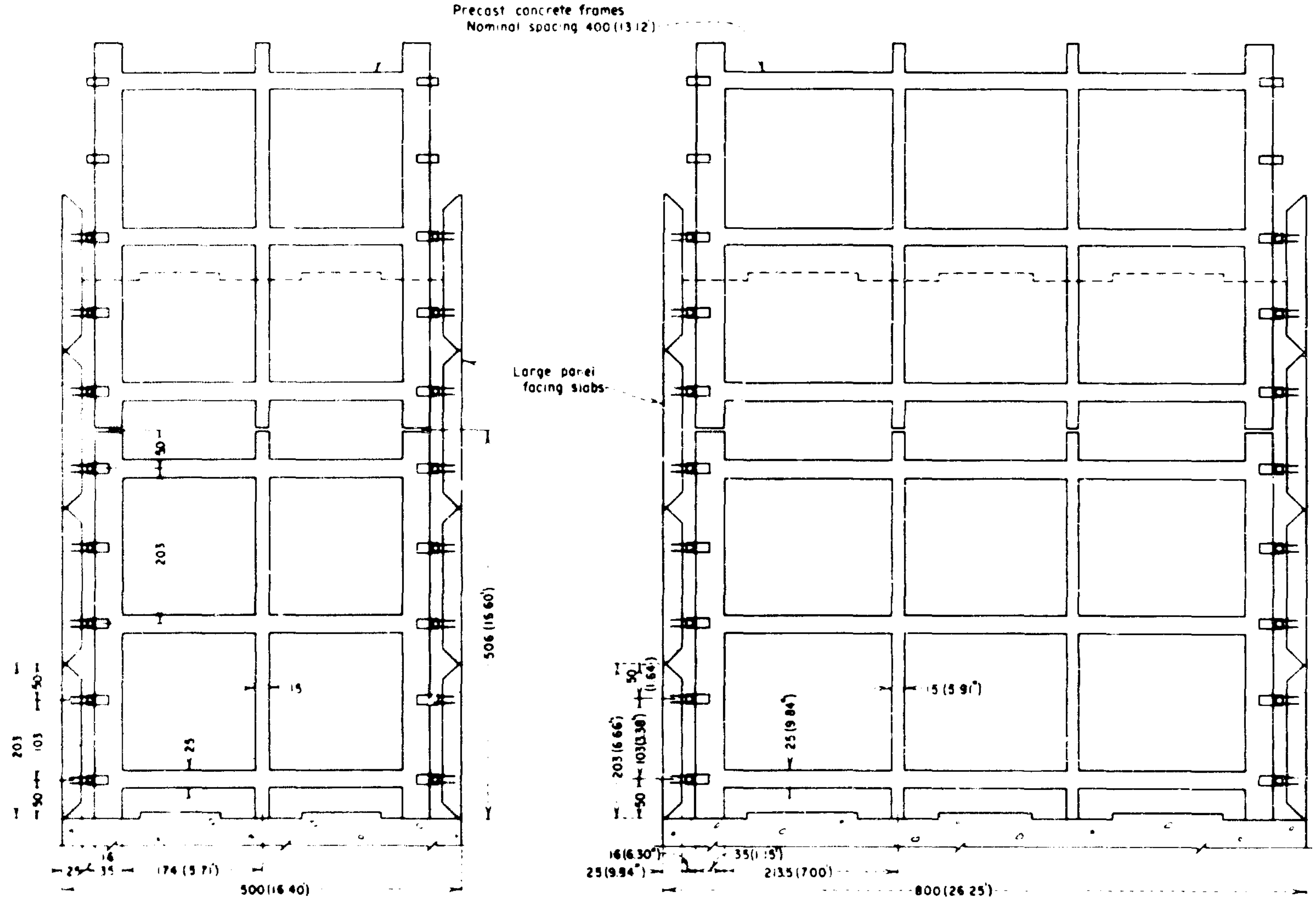
Large panel facing slabs are precast reinforced concrete slabs of sufficient thickness and strength to carry loads between supports without the need for any external trusswork. The structure reinforcement in whole or in part is placed in the slab thus acting to strengthen the slab to withstand handling and erection loads and to reinforce the completed structure. For vertical face slabs, the horizontal reinforcement of the building may be incorporated in the slab and the vertical reinforcement tied to the inner face of the slab before or after erection (Figure 4). The usual reinforcement for anchoring the slab to the structure concrete is required. Note in Figure 4 the reduced thickness of the ends of the slab, providing for splicing of the projecting horizontal structure reinforcement without leaving a wide gap between forms.

Form panels are supported by and anchored in position to precast concrete frames extending normal to the panels (Figure 5). These frames take the thrust due to the pressure of fresh concrete on the forms and can be utilized to support trestlework for concrete placing equipment. The slabs are designed as continuous beams supported by the frames. The slab and installation shown in Figures 4 and 5 represent designs proposed but not actually constructed. Some smaller slabs of this type have been used in construction.



LARGE PANEL FACING SLAB INCORPORATING HORIZONTAL STRUCTURE REINFORCEMENT

FIGURE 4



TYPICAL WALL SECTIONS
SUPPORT FRAMES FOR LARGE PANEL FACING SLABS

FIGURE 5

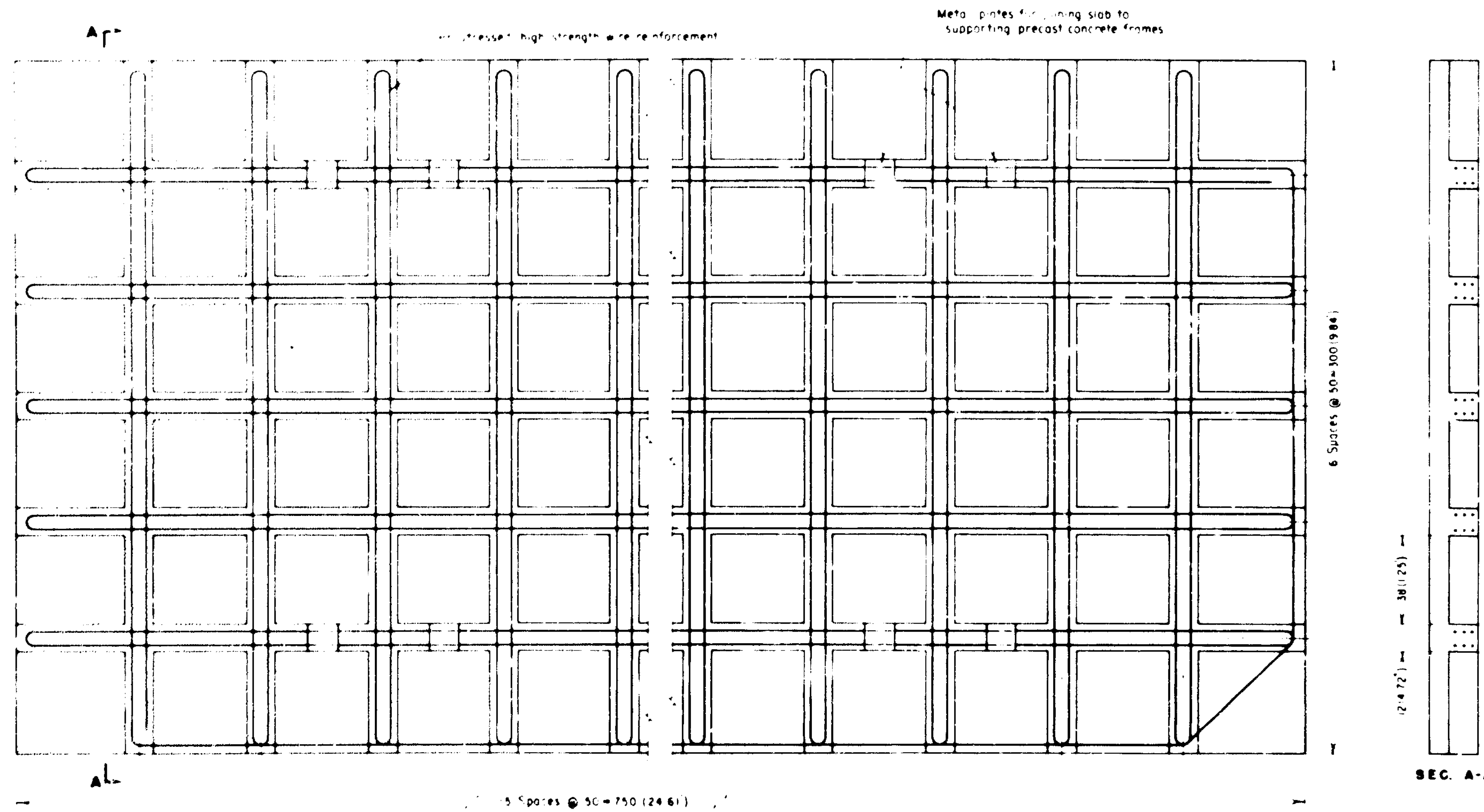
Although large panel facing slabs are heavier than thin facing slabs, their design permits a savings in reinforcement steel and a savings in the time required for placing and tying structure reinforcement and for erecting forms.

Other large structural panels reinforced with prestressed steel, in one or both directions, have been designed and constructed. They contain only part or none of the main structure reinforcement. They consist of a thin face with integral concrete ribs in one or both directions extending from the back. A proposed design of a prestressed ribbed slab 7.50 meters (24.6 feet) long by 3.00 meters (9.84 feet) wide with ribs spaced at 50-centimeter (19.7-inch) centers each way is shown in Figure 6. It was planned to construct these slabs by the method of continuous prestressed reinforcement.

Bearing facing slabs are long-span self-supporting units generally used for forming horizontal surfaces. They are designed to reduce or eliminate the need for supporting shoring. Several types have been constructed including:

Structural slabs for spans of 4.00 meters (13.1 feet) to 5.00 meters (16.4 feet) without shoring and for longer spans with intermediate supports.

Thin slab and reinforcing steel truss combinations with the slab either suspended from the truss or cast as an integral part of the truss bottom chord.



P L A N

PRESTRESSED RIBBED SLAB

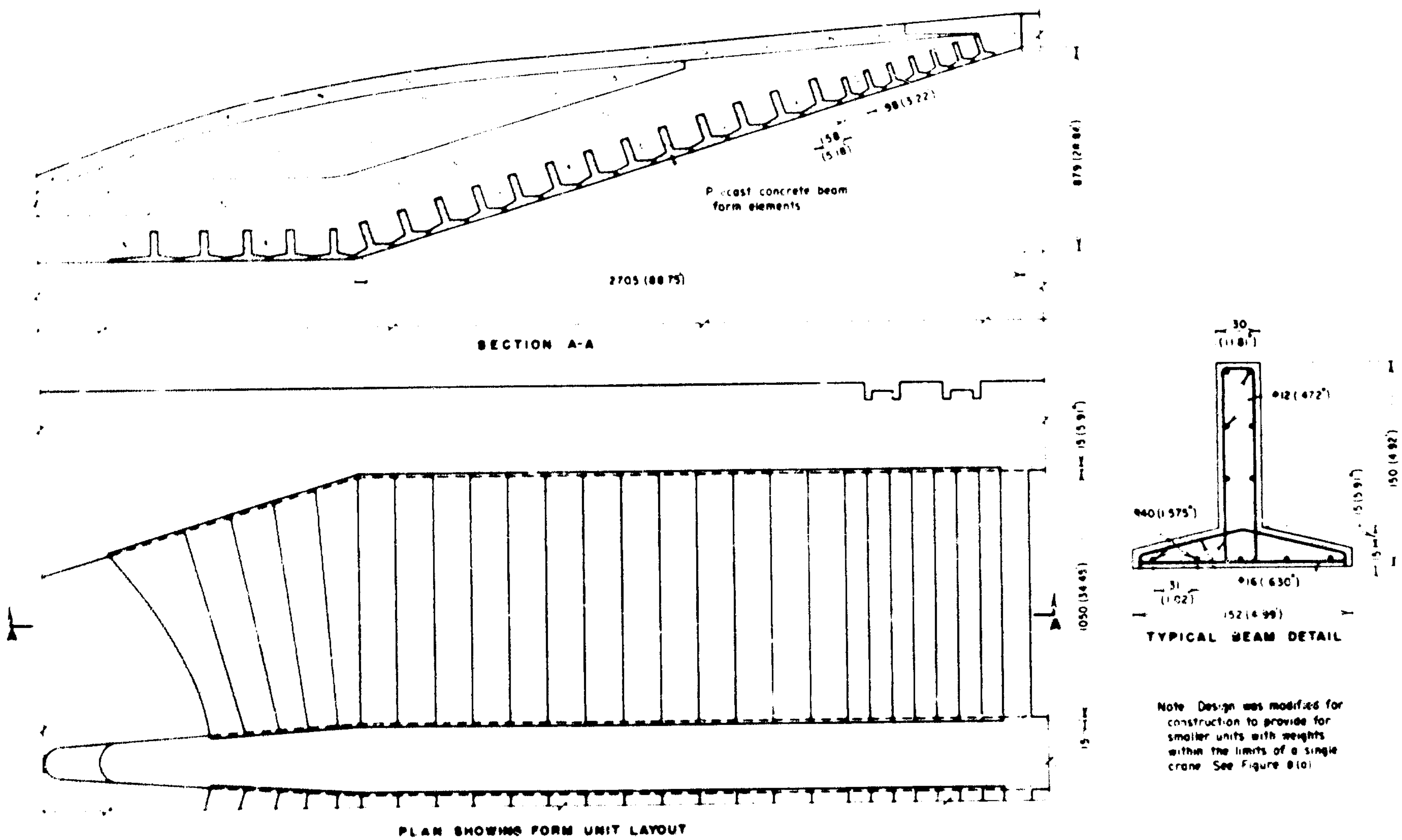
FIGURE 6

Concrete beams in the form of inverted tee beams, multiple-tee beams, or ribbed slabs (see Figures 7 and 8). These have been constructed for spans of up to 12 meters (39.4 feet). Prestressed reinforcement should be of particular advantage in beam-type forms in eliminating tensile stresses in the thin facing flange of the tee sections. Beams and thin slab units may be designed to form single curvature surfaces, as shown in Figure 9.

STRUCTURAL DESIGN

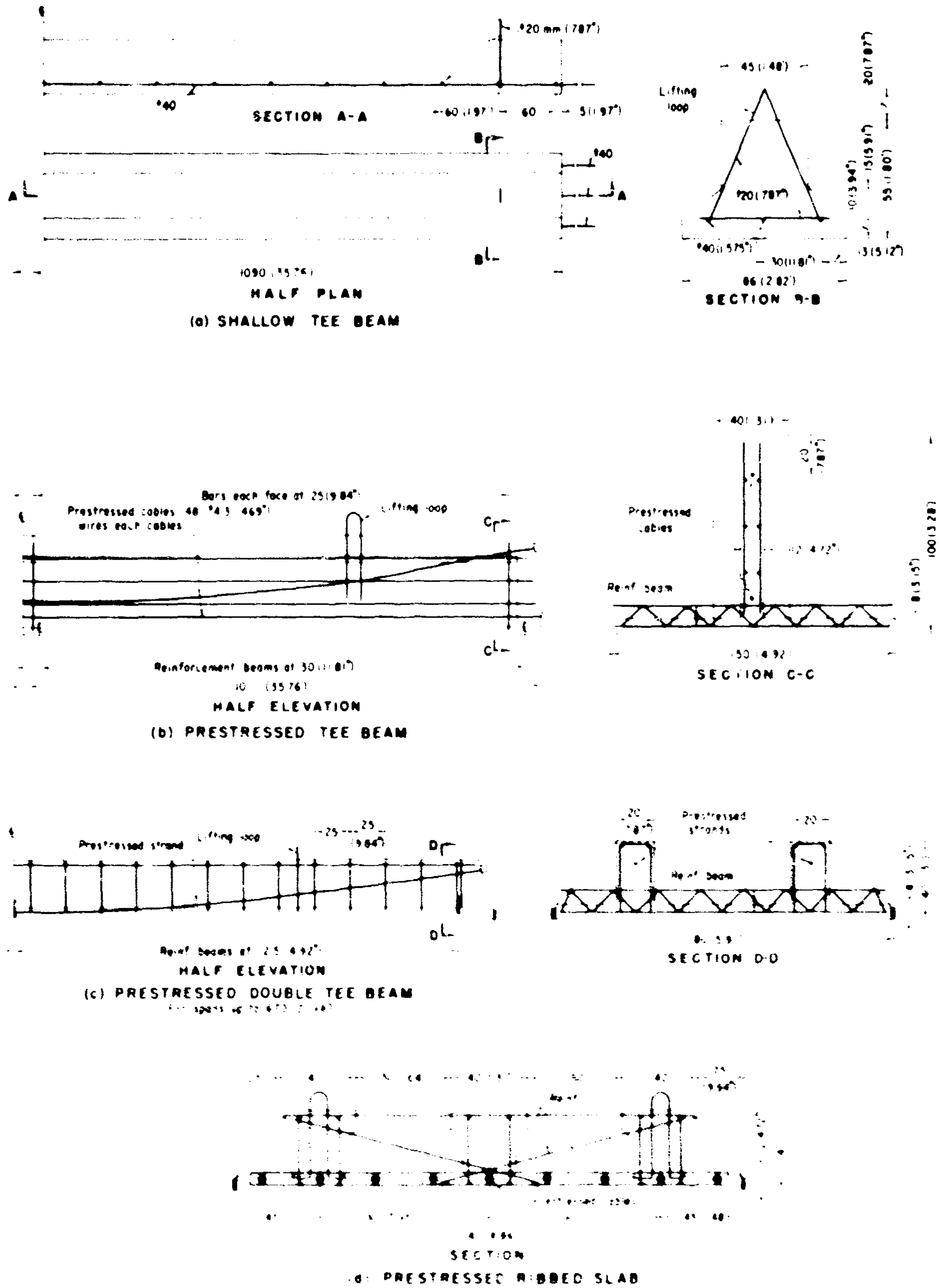
The structural design of precast concrete forms follows currently accepted methods of design and analysis for slabs and beams. Thin facing slabs have usually been designed as unreinforced slabs supported by ties spaced on approximately 1.00-meter (3.3-foot) centers each way. One design incorporated transverse reinforcement in the slab permitting the transverse spacing of the ties to be twice that of the longitudinal spacing. (See Figure 10.) Another design also included longitudinal reinforcement in the slab, further reducing the number of ties. Designs have also been prepared utilizing prestressed reinforcing in thin facing slabs to reduce cracking and permit a reduction in thickness.

Large panel facing slabs are designed as continuous beams supported at regular intervals by rigid cross members. Structural design and analysis of various types of bearing facing slabs should utilize for each type the method most suited to its conformation and support system.

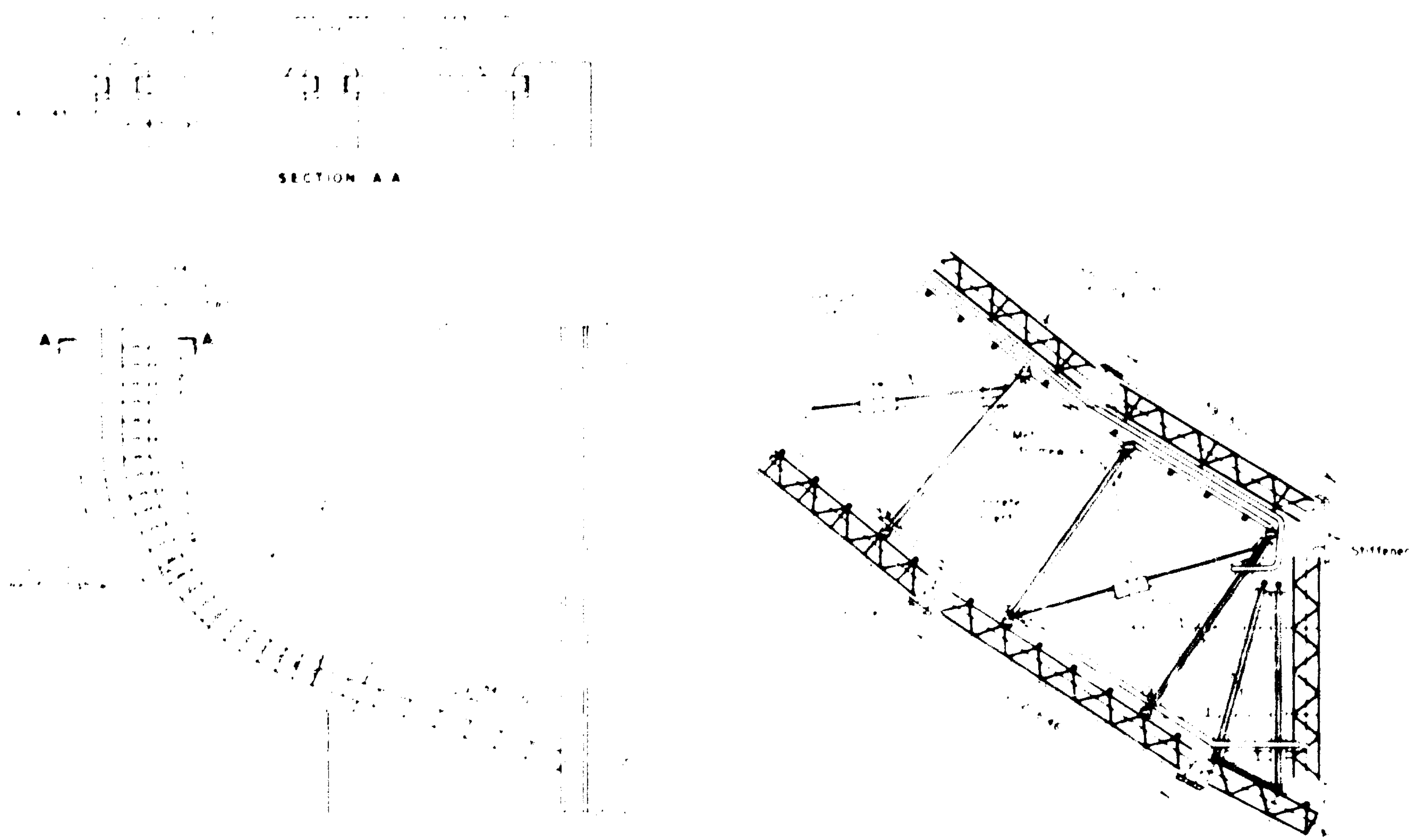


DRAFT TUBE CEILING FORMED BY PRECAST CONCRETE BEAM UNITS

FIGURE 7



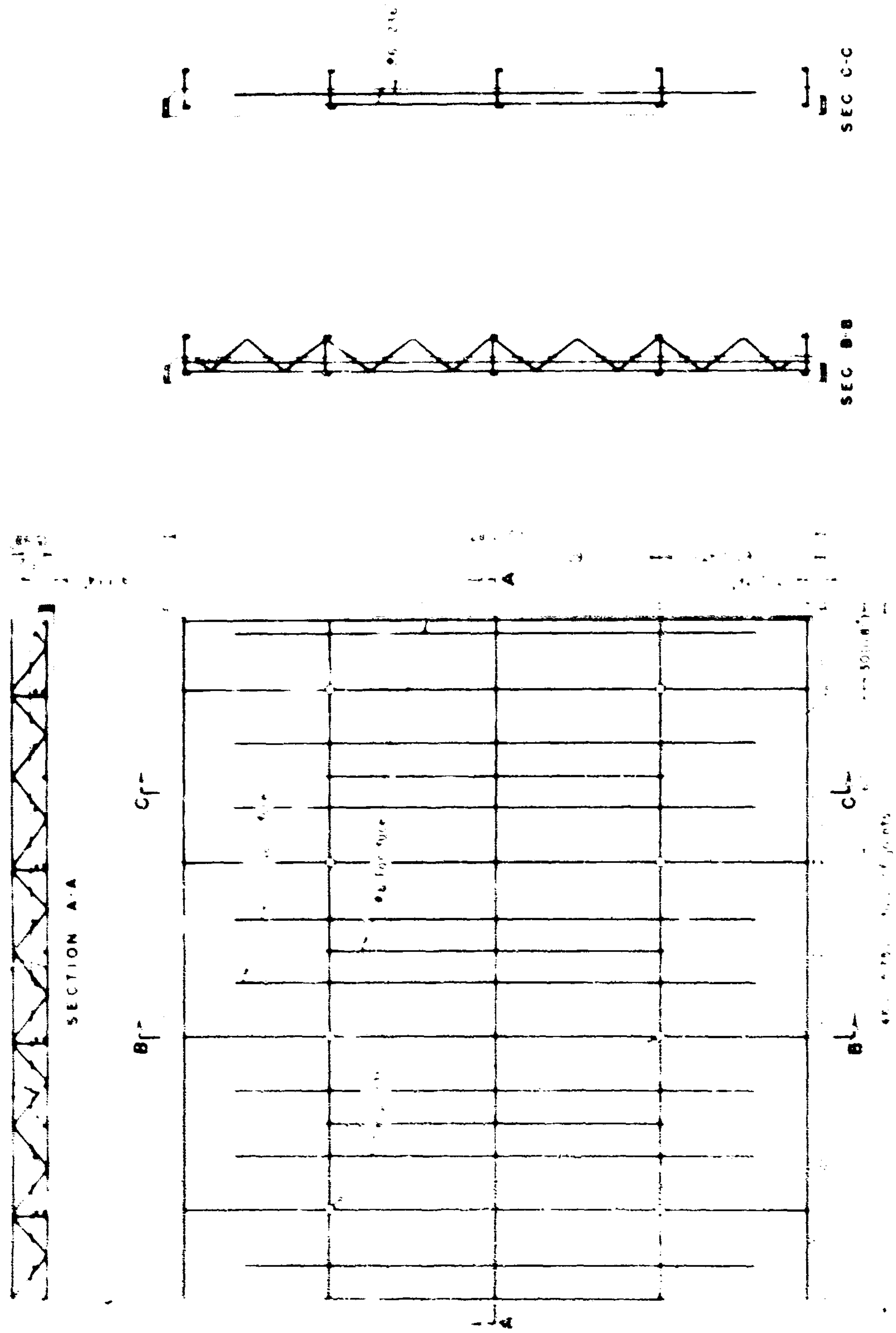
TYPICAL REINFORCED CONCRETE BEAM BEARING FACING SLABS



(a) PRECAST REINFORCED CONCRETE BEAMS (b) THIN SLAB FACING UNITS JOINED BY A METAL FRAMEWORK

FORMS FOR CURVED PENSTOCK INTAKE SURFACES

FIGURE 9



THIN CONCRETE FACING SLAB WITH TRANSVERSE SLAB REINFORCEMENT

FIGURE 10

Allowable unit tensile stresses in the concrete of 14 to 20 kilogram per square centimeter (203 to 285 pounds per square inch), minimum concrete strength (f'_c) of 250 kilograms per square centimeter (3,560 pounds per square inch), and ultimate steel strength of 2,850 kilograms per square centimeter (40,500 pounds per square inch) were used in typical designs by Soviet engineers. Loads on precast concrete forms are of two types: those due to removal of the units from the forms, transporting and handling, and erection in the structure, and those due to concrete placing operations and plant operation.

The first type involves the dead weight of the units under various support conditions such as when the units are suspended by lifting hooks or supported on one edge. The second type includes the lateral pressure of wet concrete, 2 to 2.6 metric tons per square meter (410 to 536 pounds per square foot), dynamic loads incurred during placing of concrete, stresses due to shrinkage of the structure concrete and changes in temperature, and hydrostatic pressure between the slab and the structure concrete. Anchors connecting facing slabs and structure concrete have been designed for hydrostatic pressures resulting from hydraulic heads as high as 20 meters (65.6 feet) with no allowance being made for the bond between the two. However, in tests conducted by Soviet engineers it was determined that the bond between the slab and the structure concrete exceeded the possible hydrostatic pressure in the joint by

2.5 to 4 times. Further, examination of facing slabs installed in certain Soviet plants in 1949-50 established that the bond in the joint was stronger than that between the particles of the structure concrete. In this case spalling of the slabs due to hydrostatic pressure could occur due to failure of the fill concrete regardless of the total cross section of the reinforcement bars in the joint. Apparently this structure concrete was of very poor quality.

In some instances, it might be necessary also to design units to support scaffolding and concrete transporting equipment.

BOND

To realize maximum benefit for the life of the structure from precast concrete facing forms, it is essential that the bond between the precast units and the structure concrete be as efficient as possible. This is accomplished by special treatment of the joint face, by providing anchor bars extending across the joint, and by care in placing the structure concrete. In the USSR, surface treatment consists of spreading stone chips on the contact face before completion of vibration during the manufacturing process or of sandblasting the contact face after manufacture. For one job in Austria, where the contact surface was formed, the form was coated with a special retarder before concrete placement. After 24 hours the form was removed and the slab face was subjected to an air-water jet creating a rough surface. Test cores taken

from these units after construction was completed showed the resultant bond with the structure concrete to be excellent.

Bureau of Reclamation tests were made of a concrete frame formed with 5.08-centimeter (2-inch-thick) precast slabs. The joint face of the slabs was given a minimum amount of finishing with no special treatment. The surface was relatively free of laitance due to the stiff consistency of the mix. Lifting hooks embedded in the slabs served also as shear connectors. The bond between the precast slab and the cast-in-place concrete, based on loading tests of the frame, proved to be very good. Similar experiments conducted in the USSR indicate the zigzag bars across the joint between the precast slabs and the structure concrete strengthen the bond in the joint by 60 percent or more.

In Russia, after construction is completed, facing slabs are tested by tapping for the presence of cavities in the structure concrete. One specifications calls for grouting a cavity on the water side of the structure if its face area is greater than 0.1 square meter (1.08 square feet). Grouting is accomplished at pressures of 3 to 4 atmospheres (44 to 59 pounds per square inch).

JOINTS

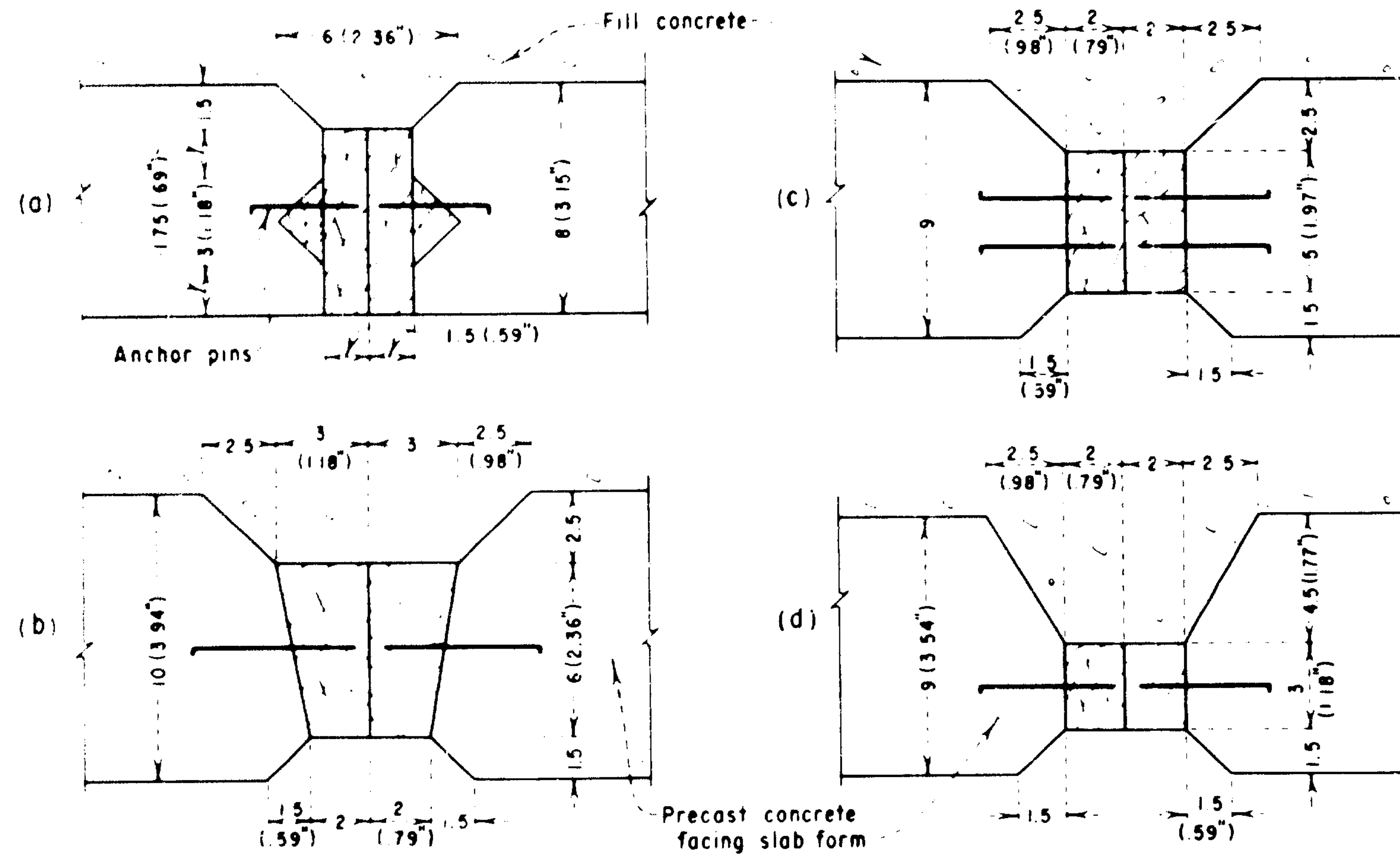
The most common system employed in the USSR for forming and finishing joints between precast concrete form slabs involves first the placement of wooden strips around the edges of the slab during manufacture. These frames remain on the unit until after the

structure concrete is placed in the erected forms and has set, giving protection to the slab edges during handling and erection operations and forming a joint between the units. One month or more after placement of the structure concrete, the wooden strips are removed by digging or pulling out with special tools; the joints are then filled with mortar. For typical details of joints so constructed see Figure 11.

Engineers Moiseenko and Sedov inspected some plants utilizing the above joint system 10 years after construction and observed many faults and failures of the joint mortar due in part to faulty installation and inadequate curing. They concluded and recommended that future joints be filled with the same concrete used to fill the block at the same time the block itself is filled. Wooden frames would be removed from the units before erection. They specified a joint 5 centimeters (1.97 inches) wide covered with reuseable wooden forms 15 by 20 centimeters (5.9 by 7.87 inches) in cross section to which are fixed ties to hold the forms in place. (See Figure 12.)

Other systems have been proposed but none provides a simple, sure method of obtaining a strong watertight joint with structure concrete when placing it in the structure. Aggregate is generally too large to fill the joint in a satisfactory manner.

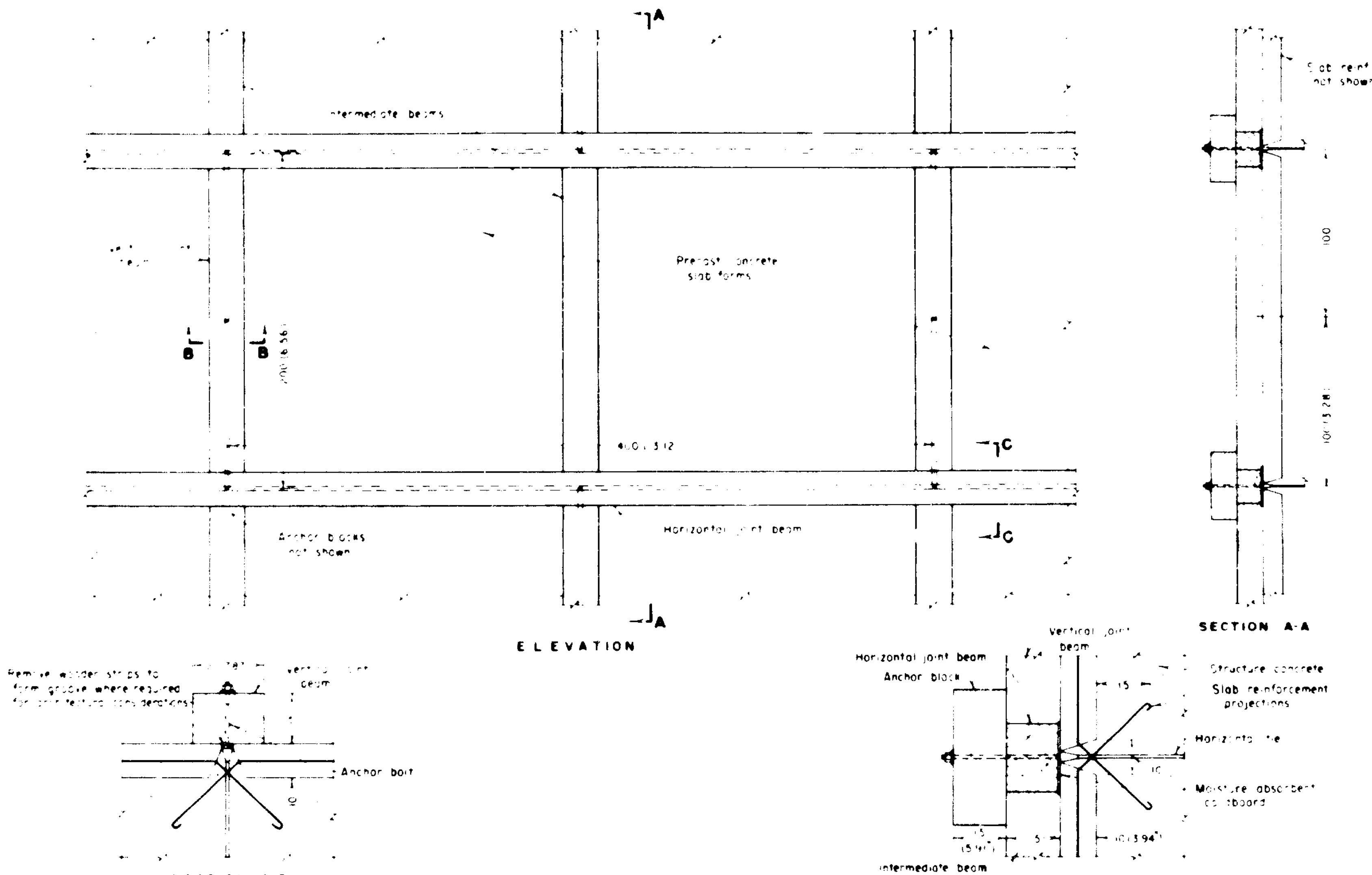
In construction of Big Muehldorf Lake Dam in Austria, form panels were lap jointed with each other on all sides. The inner



Remove wood strips one to two months after structure concrete is placed and fill with concrete mortar.

TYPICAL MORTAR-FILLED JOINTS

FIGURE 11



A PROPOSED FORMING SYSTEM FOR JOINTS FILLED WITH STRUCTURE CONCRETE

FIGURE 12

half of the joint was carefully filled with mastic prior to placing the dam concrete. The exterior portion of the joint was filled at a later time. Block joints in the dam were sealed with 6.4-centimeter (2-1/2-inch) by 1-centimeter (0.4-inch) strips of foam rubber saturated with bitumen and later grouted.

MANUFACTURE

For economical production and good quality control, a well designed plant furnished with good equipment of the proper type and capacities is necessary. The plant may be an open air plant or an indoor plant or a combination of the two depending upon the climate, the degree of permanence, and the required capacity. Reference b gives a very good description and discussion of these plants.

The basic requirements in the USSR for concrete used in the manufacture of precast facing slab forms, as outlined in Reference b, are as follows:

Minimum concrete strength.--Compressive strength as determined by tests of standard 20- by 20-centimeter (7.8- by 7.8-inch) cubes should be 250 kilograms per square centimeter (3,560 pounds per square inch).

Watertightness.--A concrete cylinder 15 centimeters (5.91 inches) high by 1.5 centimeters (0.591 inch) in diameter should resist a water pressure of 8 kilograms per square centimeter (114 pounds

per square inch) for 28 days without sign of percolation through the specimen.

Frost resistance.--Concrete units should be able to withstand 300 freezing and thawing cycles while in a state of complete water saturation.

Cement.--Portland pozzolan cement should be added to the concrete mix at the rate of 400 kilograms per cubic meter (1.79 barrels per cubic yard).

Water-cement ratio.--0.45.

Consistency of mix.--Cone slump of 2 to 3 centimeters (0.79 to 1.18 inches).

COMMENTS

It would appear that the interest and the development of the use of precast concrete formwork in the Soviet Union could be attributed in part to the inability to produce concrete on the jobsites of a quality adequate to meet the requirements of hydraulic structures. Only with the control possible, though not always attained, in manufacturing plant procedures do the Soviets produce concrete of adequate quality. Their use of precast forms is also influenced by the fact that although they export large quantities of timber they seem to be very frugal in its use at home, probably because of its high value in foreign currency. Steel for formwork is also

relatively quite expensive compared to timber or concrete. As the Soviet conception of economics and the variation of the relative values of labor, equipment, and materials in their country differ from those in the United States, we cannot necessarily accept that their conclusions as to the economy of using precast concrete forms rather than removable forms would apply in the United States.

Some instances are given of projects constructed in the Soviet Union where considerable construction time was saved in parts of the works by the use of precast concrete forms rather than removable formwork. In many if not most of the other projects utilizing precast concrete forms, other factors prevented the realization of any savings in construction time. We cannot assume that we would realize the same potential savings in time as the Soviets, as we do not know their degree of efficiency in the use of conventional removable formwork or the nature of other factors that may affect the magnitude of their time savings.

CONCLUSIONS AND RECOMMENDATIONS

Assuming that the quality of concrete in reinforced concrete structures constructed in the United States using conventional removable formwork is such as to satisfy the requirements of strength, durability, and watertightness, it follows that the basis for determining whether or not to utilize integrated precast concrete forms in such construction must be economic. The exception would

possibly be where time would be a major factor, such as in a location subject to long, severe winters and a short construction season.

Before preparing cost estimates to determine if, where, and when integrated precast concrete forms units can be economically justified, the following items should be considered:

1. The parts or elements of the structure most adaptable to construction using precast concrete forms
2. The types of form units best suited for the various parts of the structures
3. Development of designs and installation details for form units to give minimum production and erection costs consistent with their functional requirements
4. Investigation of the possibilities of reducing the quality of the structure concrete placed in the erected formwork
5. The minimum size of structure or the minimum number of form units for economical form unit production
6. Reduction or elimination of special form handling equipment not otherwise required for construction
7. Structure modifications to reduce number of odd shapes and sizes of form units
8. Possibility of elimination of waterstops and keyways in construction joints

9. Reduction of total area of construction joints by taking full advantage of the flexibility of construction joints gained by the use of precast concrete forms

In addition there is need for further research and testing of various anchor systems and methods of preparing the inside faces of form units to determine the simplest and most economical methods of obtaining adequate bond between the facing slabs and the cast-in-place concrete.

BIBLIOGRAPHY

a. Berezinskiy, A. R., Sokolova, V. F., and Alipoy, V. V., "The Utilization of Precast Reinforced Concrete in Hydrotechnical Structures," Leningrad-Moscow, 1959, translated from Russian May 1962

b. Sedov, M. P., "Protective Reinforced Concrete Shells in Hydrotechnic Constructions," Leningrad-Moscow, 1958, translated from Russian, Jerusalem 1962, Israel Program for Scientific Translation, IPST Catalog No. 594

c. Ermolov, V. V. and Petrov, G. D., "Formwork for Massive Concrete Structures in Hydro Developments," Second Edition Leningrad-Moscow 1954, translated from Russian 1963, IPST Catalog No. 593

d. U. S. Army Engineer District, Little Rock, Corps of Engineers Technical Report CW1, Item 624, "Review of Available Information and Cost Study," August 1963

e. Backstrom, J. E. and Mitchell, L. J., "Prestressed Slabs for Concrete Forms," USBR Paper presented to 7th Annual Convention of the Prestressed Concrete Institute, October 18, 1961. Published in Prestressed Concrete Institute Journal, June 1962, USBR Library No. 101,229

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures, this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the [illegible] (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will [illegible]nd increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.404687	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358	Cubic centimeters
	0.946331	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter